

HUMAN FACTORS MODEL CONCERNING THE MAN-MACHINE INTERFACE OF MINING CREWSTATIONS

James P. Rider and Richard L. Unger

U.S. Department of the Interior
Bureau of Mines
Pittsburgh Research Center

Abstract

The U.S. Bureau of Mines is developing a computer model to analyze the human factors aspect of mining machine operator compartments. The model will be used as a research tool and as a design aid. It will have the capability to perform the following: simulated anthropometric or reach assessment, visibility analysis, illumination analysis, structural analysis of the protective canopy, operator fatigue analysis, and computation of an ingress-egress rating. The model will make extensive use of graphics to simplify data input and output. Two dimensional orthographic projections of the machine and its operator compartment are digitized and the data rebuilt into a three dimensional representation of the mining machine. Anthropometric data from either an individual or any size population may be used. The model is intended for use by equipment manufacturers and mining companies during initial design work on new machines. In addition to its use in machine design, the model should prove helpful as an accident investigation tool and for determining the effects of machine modifications made in the field on the critical areas of visibility and control reach ability.

1. Introduction

Because of the unique environment in underground mining, mine workers are exposed to a variety of conditions and stresses that are not common in other industries. Mine equipment is usually massive in size and built to withstand a tremendous workload. Often the design of the mining equipment stresses functionality and production over human operator considerations. This has resulted in mining machines where visibility is at a premium and often the operators must lean outside the safe confines of the operator compartment in order to see and operate the equipment as shown in figure 1. Controls are often unlabeled and placed where they are difficult to reach and distinguish from one another; in panic situations, the wrong control is frequently activated. Because of height restrictions in many underground mines, the operator works in an awkward reclined seating position which leads to fatigue and stress. The Mining Equipment Safety Laboratory of the Mine Safety and Health Administration (MSHA) analyzed all fatal accident reports involving underground coal mine mobile equipment for the years 1972 through 1979. During this period, 350 fatalities were investigated and 126 of the fatalities were attributed to improper control design, inadequate visibility from the operators's cab, inadequate compartment size, operators leaning outside the cab, machines without operator compartments, and poorly designed seats. In

summary, approximately 36% of the fatalities involving underground mobile mine equipment for the seven years in question relate to improperly designed operator compartments (1).

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Figure 1 - Miner working in a cramped, visually obstructed environment.

The U.S. Bureau of Mines is charged with conducting research to increase both the safety and productivity of the mineral industries. As part of this research, the Bureau is developing a computer model to assist in the design and analysis, from a human engineering standpoint, of underground mine equipment operator stations. The model known as CAP (Crewstation Analysis Programs) is to be used by original equipment manufacturers and mining companies for the preliminary design work on new machines in terms of good ergonomic design principles. With the implementation of the model, the designer will be given flexibility to experiment with the design of new equipment which is not practical using conventional techniques.

For the sake of simplicity, CAP can be thought of as being composed of the following sections :

1. Input (machine and sample population).
2. Anthropometric analysis.
3. Visibility analysis.
4. Reach analysis.
5. Illumination analysis.
6. Canopy structural analysis.

The initial module defines the operator compartment, mining machine, mine layout and a sample population. The anthropometric section identifies the working posture of the miner and the reach envelop associated with the operator. The operator's field of visibility is determined in third module. The model uses an adaption of the Crewstation Assessment of Reach (CAR) model developed by Boeing Aerospace Corporation (2) to determine whether the controls are reachable for a given population. The fifth module provides an assessment of the illumination requirements of the machine's lighting system and the final section determines the structural strength of the compartment's canopy.

This paper briefly describes the input, reach, visibility, and illumination sections of the model. Interested readers are invited to contact the Bureau of Mines, Pittsburgh Research Center, for more information on the CAP model.

2. Machine and Sample Population Input

Before any analysis can begin, a 3-D, simplified model of the operating station and related machine must be entered into the computer. Often times entering the machine data is a tedious and time consuming process. For this reason a decision was made to develop a method to input the data as quickly and accurately as possible so users may concentrate their efforts on the ergonomic analysis of the machine and compartment. The method chosen takes advantage of engineering layouts drawn in an orthographic projection format and makes use of a digitizing graphics tablet. Polygonal geometries are digitized and the model performs a spatial 3-D reconstruction using a series of functions which identify specific 3-D geometries in the orthographic projection. The program does not contain any high level sophisticated network of geometric concepts but uses a concept similar to the one used by Lafue (3) and Thornton (4). By using the function menu to identify 3-D geometric shapes such as polyhedrons, right circular cylinders, spheres, and wedges the program reconstructs a 3-D object from 2-D orthographic projection drawings (figure 2).

Most of the analysis sections of the CAP model require a sample population for testing. The model allows the user to enter 12 external anthropometric measurements of one or more individuals to build a sample population. Once the 12 measurements have been entered, the model determines the validity of the input and responds accordingly. If the anthropometric input is invalid the model will prompt the user to re-enter the specific measurement in question. If valid data exists the procedure will prompt the user to enter another individual's anthropometric measurements or exit and save the population data base. The 12 external measurements for the sample population are transformed into internal link lengths and link circumferences to create a 3-D link-man. The link-man used in the CAP model is a version of the original link-man in the CAR program (2). Each link is a straight line segment between centers of joint rotation corresponding to human bone structures. The link-man consists of 31 links and is based on work done by Boeing Aerospace Corporation to develop the BOEMAN model (5). CAP computes the link-lengths from external anthropometric measurements through a series of transformations derived primarily from Dempster's (6) analysis of anthropometric data.

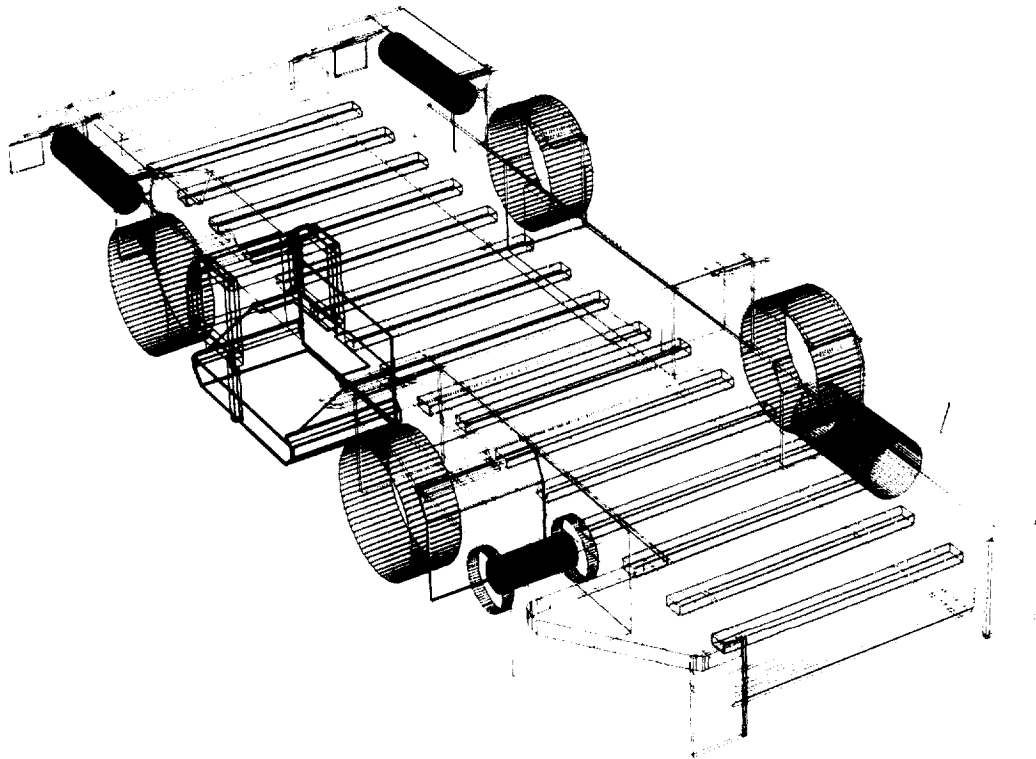


Figure 2 - A 3D representation of an underground haulage vehicle.

Once the input of the machine, compartment and the identification of the sample population is complete, the user is free to choose any analysis section desired. The flexibility of the model will allow the user to modify either the machine input or population sample based on the analysis results.

3. Anthropometric/Reach Analysis

The location of the operator and the placement of the controls is essential in the ergonomic design of operator compartments. The reach analysis sections of the model addresses both issues by using an adaption of the CAR model to position the operator in the compartment and tests if each control is reachable. It consists of a control data input module which define key parameters needed to perform the reach study, and a link-man module which define the anthropometric measurements of a sample population. A tabular printout indicates the percentage of the sample population capable of reaching the defined controls.

The reach analysis module constructs a link-man to reach for a specific point in space defined by a control location. The link-man is built using a link by link approach. The building begins at the lumbar joint which is a function of the seat reference point, the seat pan and seat back angles, and the operator's clothing. Each link is added to the previous link, with the links pointing in the direction of the defined reach point. The model takes

into consideration the operator's clothing effect which reduces the angular limits of motion for each link, and alters the link lengths and the position of the joints.

Table 1 - Control Summary Report

Control Name	Hand Foot	Harness Lock	Location/ Required Movement			% Not Accom	% Accom
			X	Y	Z		
STOP BUTTON Zone 3	LH	UNLK	14.5	-11.0	4.3	0.0	100.0
START BUTTON Zone 3	RH	UNLK	16.5	-11.0	4.3	0.0	100.0
FORKLIFT TILT Zone 3	RH	UNLK	32.0	-4.5	11.5	10.0	90.0
		Average	-0.3	-0.1	0.1		
		Worst Case	-0.9	-0.2	0.3		
HEADLIGHTS Zone 3	LH	UNLK	37.5	6.0	9.5	48.0	52.0
		Average	-0.7	0.0	0.2		
		Worst Case	-2.0	0.1	0.7		

The control analysis identifies the name, reach point location, body part used in the reach assessment, grip associated with the body part, and the harness condition for each of the defined controls. It displays the percentage of the sample population capable of reaching each control. In the case of the sample population not being able to reach the control, the program will display the average and worst case distance from the last link to the control's reach point location as shown in table 1.

4. Visibility Analysis

Because of the working environment in underground mining, operator visibility is usually at a premium. To address this problem, the Bureau sponsored research to analyze the visual requirements of mobile mining equipment and to assess the requirements through a computer model. A task analysis to distinguish the visibility requirements for a machine, i.e., what needs to be seen, from the field of visibility, i.e., what can be seen (7) was conducted. The visual requirements were defined in terms of specific locations known as visual attention locations (VALs). Using this method the VALs are specified with reference to a specific machine point and by identifying the VALs in this fashion, the location of the visual features are independent of the length, width, and height of the machine. Figure 3 displays the VALs associated with a underground haulage vehicle (shuttle car) in the fore-aft and lateral planes.

Before analysis can take place, the physical configuration of the operator compartment along with the related machine must be entered into the computer. The model will prompt the user to select and enter the digitized machine and the related crewstation database. The program queries the user for

the operator's eye position or designed eye point (DEP), and the focus point. The model will calculate the DEP by vertically building successive links dependent on the defined anthropometric measurements. The focus is defined to be a point in space which forms a line of sight vector with the design eye point. The operator's field of visibility is an important parameter in the analysis of the visual requirements. The recommended visual envelope for an operator to view a working display should be within a 30 degree cone around the principal line of sight (8).

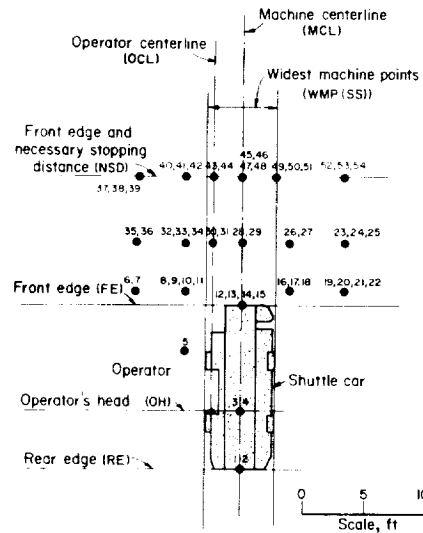


Figure 3 - Visual attention locations (VALs) in the fore-aft and vertical planes of an underground haulage vehicle.

Once the operator's eye view, focus point and the visual envelope dimension has been identified, the model allows the user to create an operator's eye view of the surrounding environment for an assessment of visibility of the VALs. The view from the operator's station is drawn, taking into account the field of vision, focus point and eye position. The user notes which VALs are visible and what modifications may be necessary in the machine design. The analysis is performed repetitively, with the user making judgments as to where the three-dimensional link-man should look. Figures 4 and 5 illustrate views from the cab of a shuttle car.

5. Illumination Analysis

The model addresses the lighting problem by providing the mining industry with a computerized method of evaluating mine illuminations systems. Proposed lighting configurations may be quickly analyzed without resorting to time consuming methods of building physical mockups and taking manual lighting readings. The model analyzes any illumination system relative to an underground mining machine and calculates the incident illuminance or

illumination (in footcandles) levels on any surface surrounding the machine. The calculations are performed so that they compare with MSHA's method for evaluating a mine illumination system.

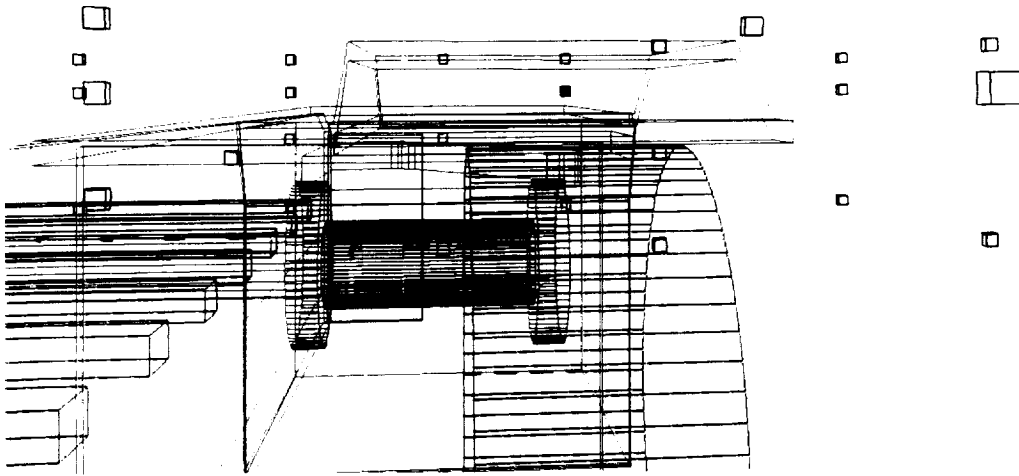


Figure 4 - A 5% female sitting in an operator compartment of a shuttle car looking at VAL #41. Note the VAL is obstructed.

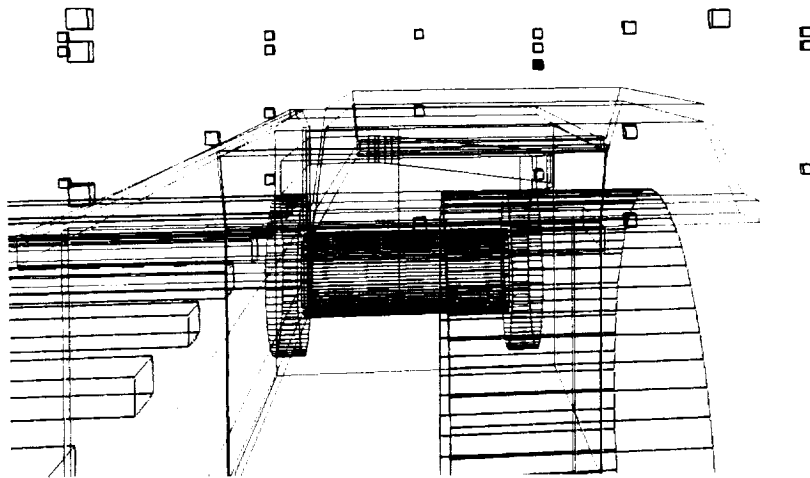


Figure 5 - A 95% male sitting in an operator compartment of a shuttle car looking at VAL #41.

In calculating incident illuminance levels, the model simulates the method of measurement used by MSHA's standard test and evaluation approach. The basic formula for calculating the illumination at any point around a machine is:

$$E = I/D^2$$

where :

E = illuminance, footcandles

I = intensity of the light along the vector between the light source and the point where the light is being measured, candles

D = distance between the light source and the point, feet

The effect of objects in the path of the light source along the location of the measurement point must be taken into consideration when performing an illumination analysis. The illuminance at a specific point is the vector sum total of the illuminance from all luminaries contributing light to that point. Light is considered to a vector originating at the lamp and ending at the measurement point. If the light vector intersects a plane of the machine before reaching the measurement point, the effects of that light are canceled out of the illumination equation. MSHA requires that incident light measurements must be taken for each 2 by 2 ft area on the mine surfaces that have to be illuminated. The model divides each of the defined surfaces in a rectangular grid, 2 ft apart and computes the incident illumination level at each point. It determines the average illuminance in each square by averaging the four grid points associated with each square. Any value that is below the minimum permissible level will be marked in the grid and displayed to the user.

6. Conclusion

Original equipment manufacturers and mine operators will have the capability to use the Crewstation Analysis Programs (CAP) model as a research tool and as a design-aid in the development and modification of new and existing mining machines. The model has the capability to quickly analyze machine mounted illumination systems, identify the visual requirements of mining machines, maximize the operator's visibility, and optimize the location of the controls to accommodate an operator sample. This may allow the designers an opportunity to experiment with the development of new equipment and aid designers to better human engineer underground mining equipment.

7. References

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